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# GAP TESTS AND HOW THEY GROW

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Abstract

Available data from four different gap tests were compared. The study indicated a linear relation between the critical gap lengths (50% point) of the NOL LSGT and those of each of the other three tests, hence a linear relation for any pair of the 4 tests.

On the other hand, the approximate equivalency curve between the 50% gaps of the NOL LSGT and those of the recently developed expanded LSGT has been drawn with some curvature. The reasons for this are presented, and the detonation properties leading to increased size of the gap test are described. Finally, the recently developed "super" gap test is compared to the others and its objective considered.

For well over a quarter of a century, gap tests have been used to assess the relative shock sensitivity of explosives. A gap test consists of an explosive donor followed by a solid attenuator followed by an explosive acceptor, the test material. The attenuator thickness is varied until detonation occurs in 50% of the trials. This 50% point or critical thickness measures the relative shock sensitivity in the particular test configuration. The test may be confined or unconfined, calibrated or uncalibrated, witnessed by steel plate or pipe or other explosives. In fact, the test had no sooner been invented, than various experimenters started modifying it until now dozens of gap tests exist.

Recently, however, an additional complication has been introduced with the advent of a group of materials known as insensitive high explosives (IHE). Some of these cannot be initiated in the more conventional gap tests. Consequently, larger and larger gap tests have been designed to test IHE.

It is the objective of this paper to show that there are unexpected correlations between gap tests of very different designs, to show why testing of IHE leads to larger tests, and to discuss two recent large tests: the expanded large scale gap test (ELSGT) and the "super" gap test.

Since our largest data base is for the NOL large scale gap tests, that test is shown in Figure 1 where one can see the series: donor, gap, acceptor, common to all such tests. Table 1 tabulates the differences in design of the tests with which its results are to be compared. Test 1 is the NOL large scale gap test (LSGT); Test 2 is the same with slightly different diameter and aspect ratio and without the steel confinement. That is an important difference because confinement decreases the effective critical diameter. Another comparison will be with the LANL LSGT (Test 3); it is unconfined and also uses a different attenuator: Dural instead of polymethyl methacrylate (PMMA). The final comparison is between the NOL LSGT and a new test developed by Forbes and coworkers, the IHE gap test (Test 4). As you can see in the table, this latter test has a diameter about one third that of the former, and although the steel cylinder containing the acceptor is thinner than that of the large scale gap

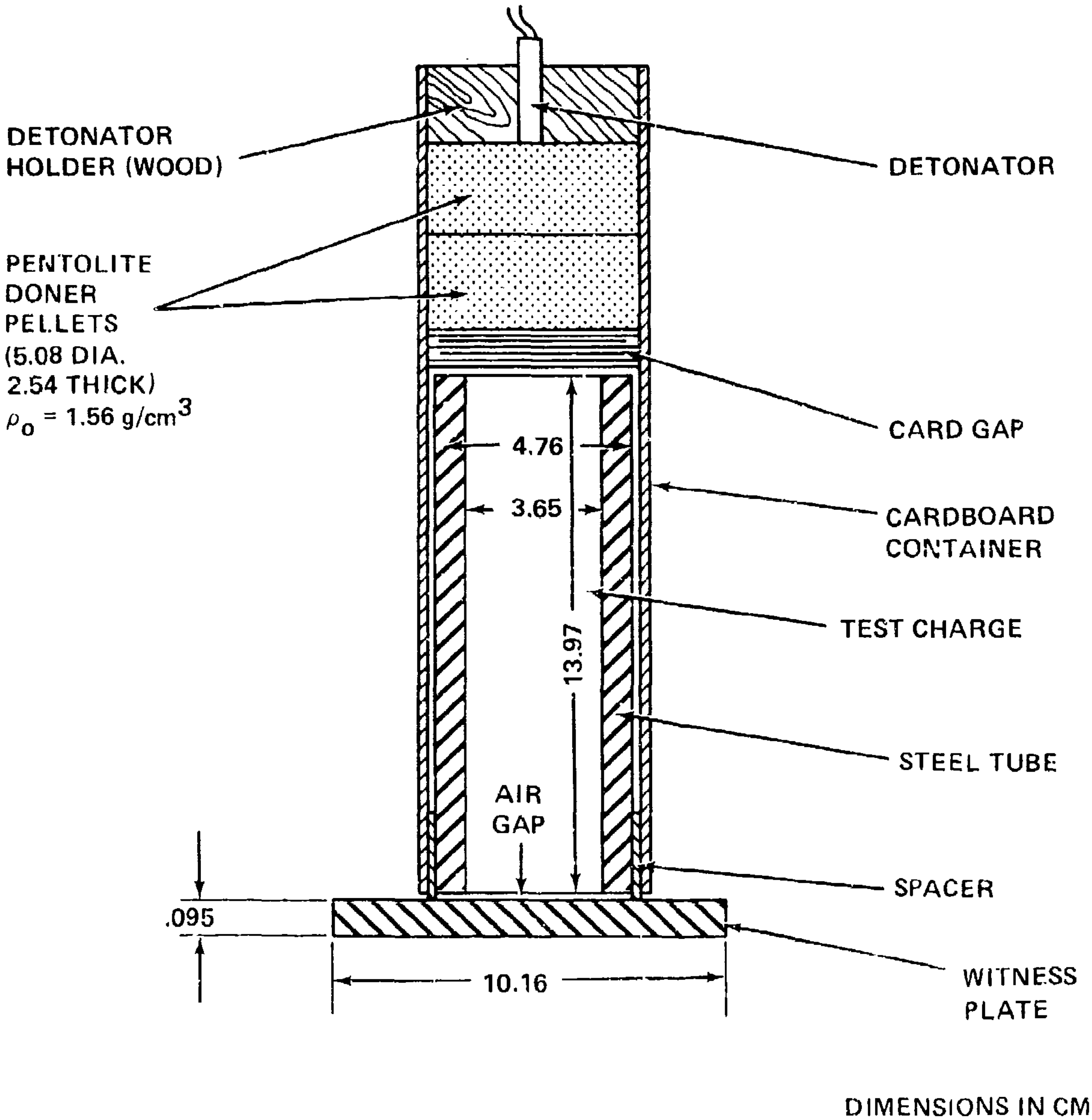



FIG. 1 CROSS SECTION OF GAP TEST ASSEMBLY FOR NOL LSGT

TABLE 1

GAP TESTS FOR WHICH RESULTS ARE COMPARED

| Test | Title | Diameter or ID cm | Aspect Ratio $\ell/d$ | Attenuator | Confinement cm |
|---|---|---|---|---|---|
| 1 | NOL LSGT | 3.65 | 3.83 | PMMA | 0.56 Thick Steel |
| 2 | Unconfined LSGT | 3.81 | 3.67 | PMMA | None |
| 3 | LANL LSGT | 4.13 | 2.46 | DURAL | None |
| 4 | IHE Gap Test | 1.27 | 4.00 | PMMA | 0.318 Thick Steel<br>1.59 Thick PMMA |

Witness is steel plate or block for each test.

TABLE 2

COMPARISON OF RESULTS FROM CONFINED

UNCONFINED NOL LSGT

| Material | $\rho_0$ g/cm$^3$ | 50% Gap[1] Confined (in. x $10^2$) | 50% Gap[1] Unconfined (in. x $10^2$) |
|---|---|---|---|
| DINA-c | 1.60 | 279 | 226 |
| Comp B-c | 1.70 | 201 | 143 |
| TNT-c | 1.61-2 | 135 | 73 |
| Pentolite-c | 1.67-8 | 273-301 | 255-266 |
| RDX-p | 1.64 | 323 | 285 |

test, its ratio wall thickness to ID, is 1.6 times greater. Table 2 and Figure 2 show the comparison between standard LSGT results and those from the non-standard, unconfined test. As Figure 2 shows, there is a definite correlation between the 50% gaps for the five explosives (4 cast and 1 pressed) that have been run in both tests. Table 3 and Figure 3 show a similar correlation between NOL LSGT values (L) and LANL LSGT (L') values for cast and plastic bonded HE despite the differences in test dimensions

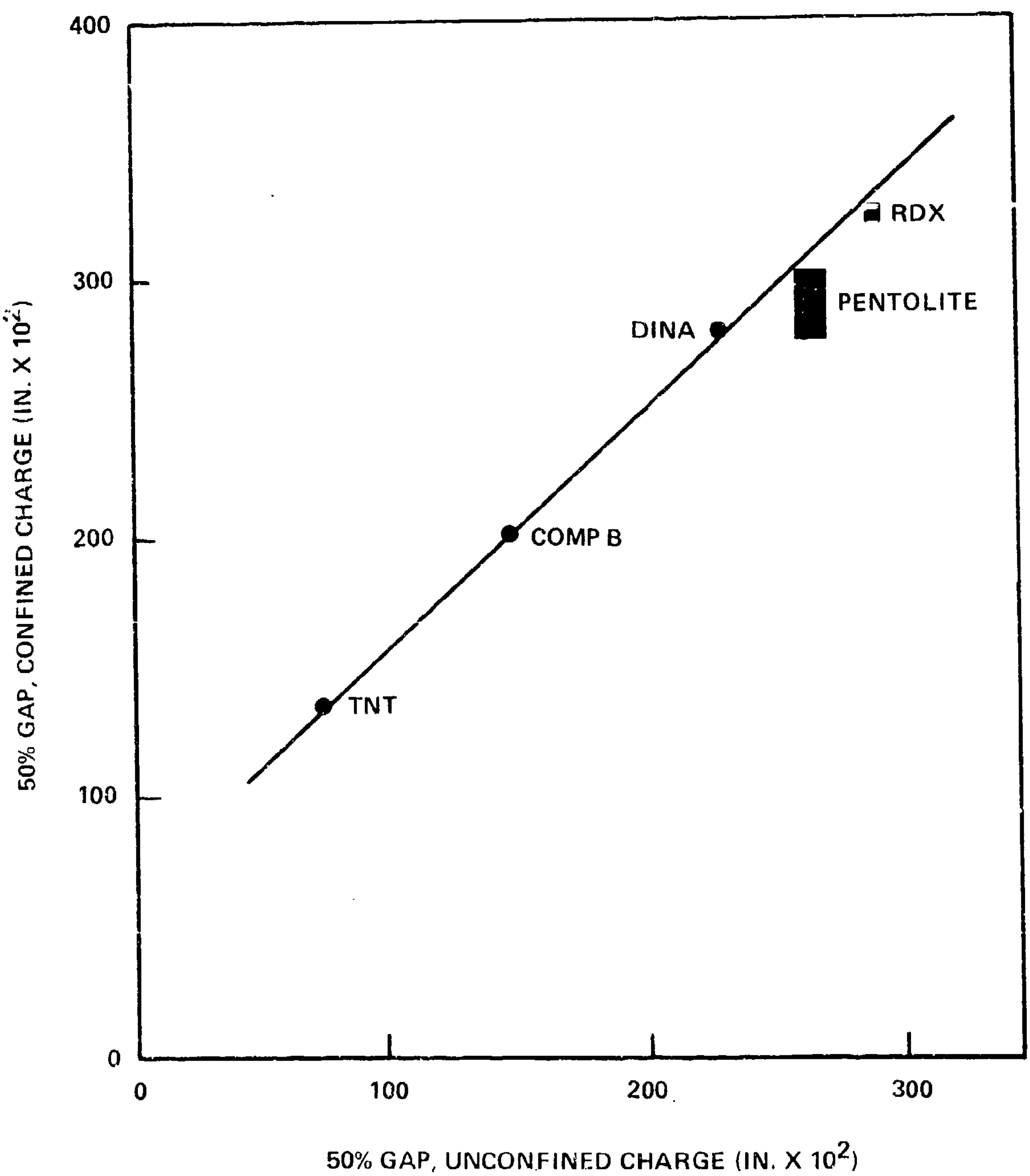



FIG. 2 COMPARISON OF RESULTS FOR CONFINED & UNCONFINED LSGT

TABLE 3

LSGT 50% GAP VALUES FOR

CAST AND PLASTIC BONDED HE

| HE | $\rho_0$ g/cm$^3$ | NOL LSGT[1] L, cards* | LANL LSGT[2] L', mm |
|---|---|---|---|
| Baratol-c | 2.62-2.63 | <123[a] | 27.30[a] |
| Comp A-3 | 1.63 | 240 | 54.51 |
| Comp B-c(A) | 1.70-1.74 | 204.5 | 43.2 |
| Comp B-3-c | 1.70-1.72 | 213 | 50.3 |
| Cyclotol-c 75/25 | 1.74-1.76 | 186 | 44.3 |
| Octol-c 75/25 | 1.81-1.83 | >217[b] | 47.32 |
| Pentolite-c | 1.70 | 273 | 64.74 |
| TNT-c | 1.62 | 129 | 28.30 |
| PBX-9404 | 1.85-1.87 | 238[b] | 55.86 |

[a] $Ba(NO_3)_2$ content 27% and 24% at NSWC and LANL, respectively.

[b] $\rho_0$ = 1.78 g/cm$^3$.

*All values corrected to current pentolite donor.

and shock attenuator. (There is no similar correlation for pressed explosives, possibly because of differences in preparing pressed charges at different laboratories).

Table 4 and Figure 4 show the linear correlation between the IHE gap test and the NOL LSGT values for the three explosives that have been run in both tests. Evidently, the IHE gap test covers the same shock sensitivity range as the NOL LSGT, but with only 4.4% the amount of test explosive. Proper test design - in this case, choice of test dimensions and confinement, can reduce the amount of explosive needed for relative shock sensitivity testing. This brings us to a related question: what is the need for larger tests?

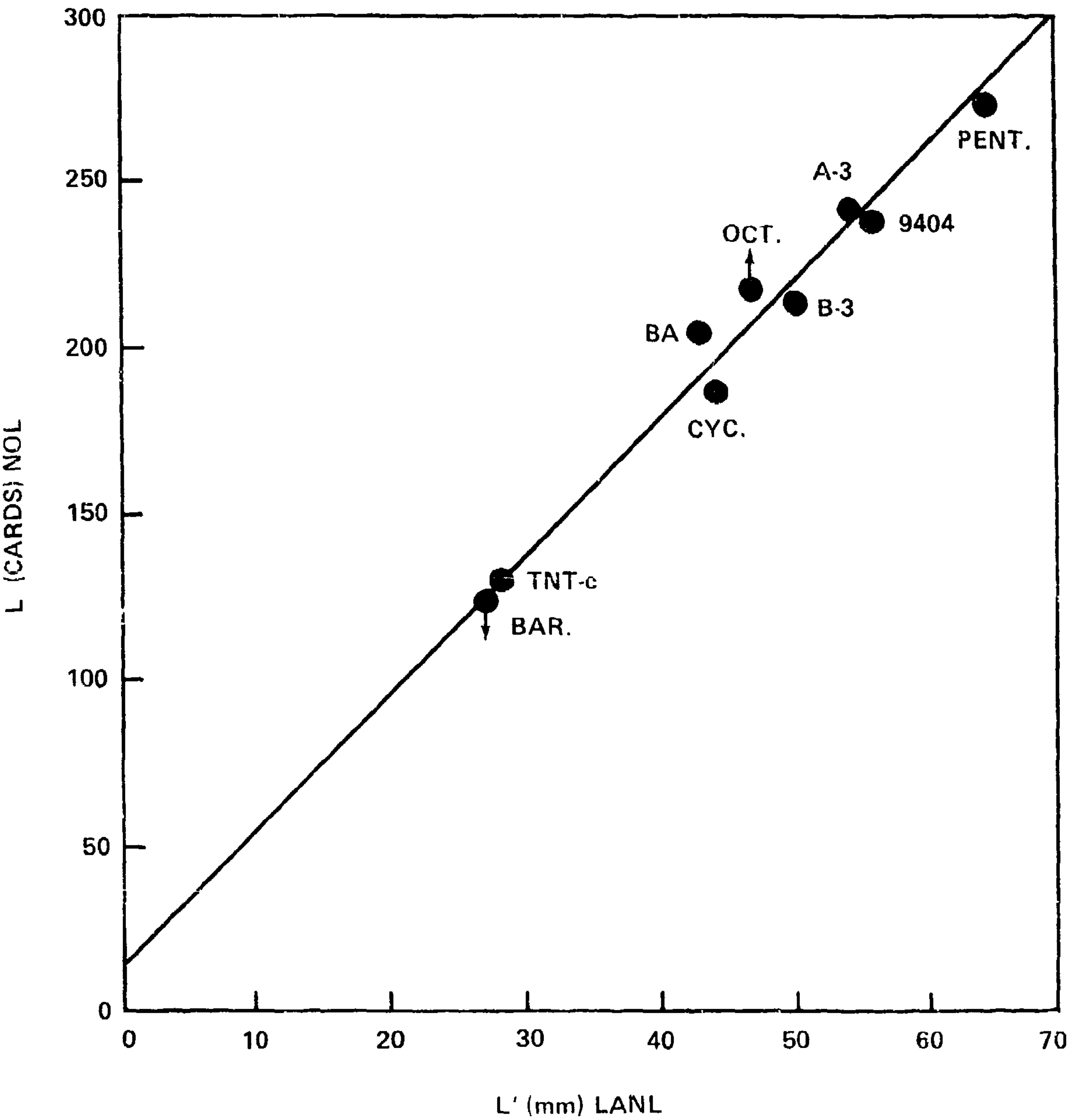



FIG. 3. COMPARISION OF NOL VS LANL LSGT VALUES

TABLE 4

COMPARISON OF NOL LSGT RESULTS WITH THOSE OF THE IHE GAP TEST

| | $\rho_0$ g/cm$^3$ | IHE[3] 50% Gap in. | LSGT' in. x $10^2$ |
|---|---|---|---|
| TATB | 1.83 | 0.92 | 78-84* |
| TNT-c | 1.61 | 1.30 | 124-135 |
| TNT-p | 1.57 | 1.92 | 193-198 |

*Higher value from G. T. West,"Classification of Explosives," Apr-June, 1976. Pantex Plant MHSMP-7630K.

To illustrate this problem, Figure 5 shows two fictitious curves of required 50% gap pressure ($P_g$) vs. charge diameter for two HE, A and B. Moreover, $2d_c(A) = d_c(B)$; $d_c$, the critical diameter, is that diameter below which propagation of steady-state detonation is impossible. My drawing leaves much to be desired, but it does show that initiation is impossible until $d \geq d_c$ and that the curve is very steep at diameters just slightly greater than $d_c$. That is why gap tests are only valid for $d \geq 3d_c$ so that the very steep portion of the curve is never used in a comparison. For example, if we use the results at $3d_c(A) = 1.5d_c(B)$ for both HE, we get a $\Delta P_g$ value much greater than if we use a diameter of $6d_c(A)$, i.e., both explosives are at $d \geq 3d_c$. The smaller difference is far more representative of the infinite diameter value. In other words, there is an infinite diameter value of gap sensitivity just as there is an infinite diameter value of detonation velocity $D_\infty$. In both cases, the values measured near $d_c$ are very different from the ideal or infinite diameter values.

The use of $P_g$ as a relative shock sensitivity measurement is an approximation of course. In the first place, it approximates $P_i$, the actual initiating pressure transmitted to the explosive. Secondly, it omits the effect of the pressure-time history of the shock. But whatever criterion may be used to estimate initiation conditions: P, $P^n\tau$*, or mass velocity u, pressure is the dominant variable.

*$\tau$ is approximate duration.

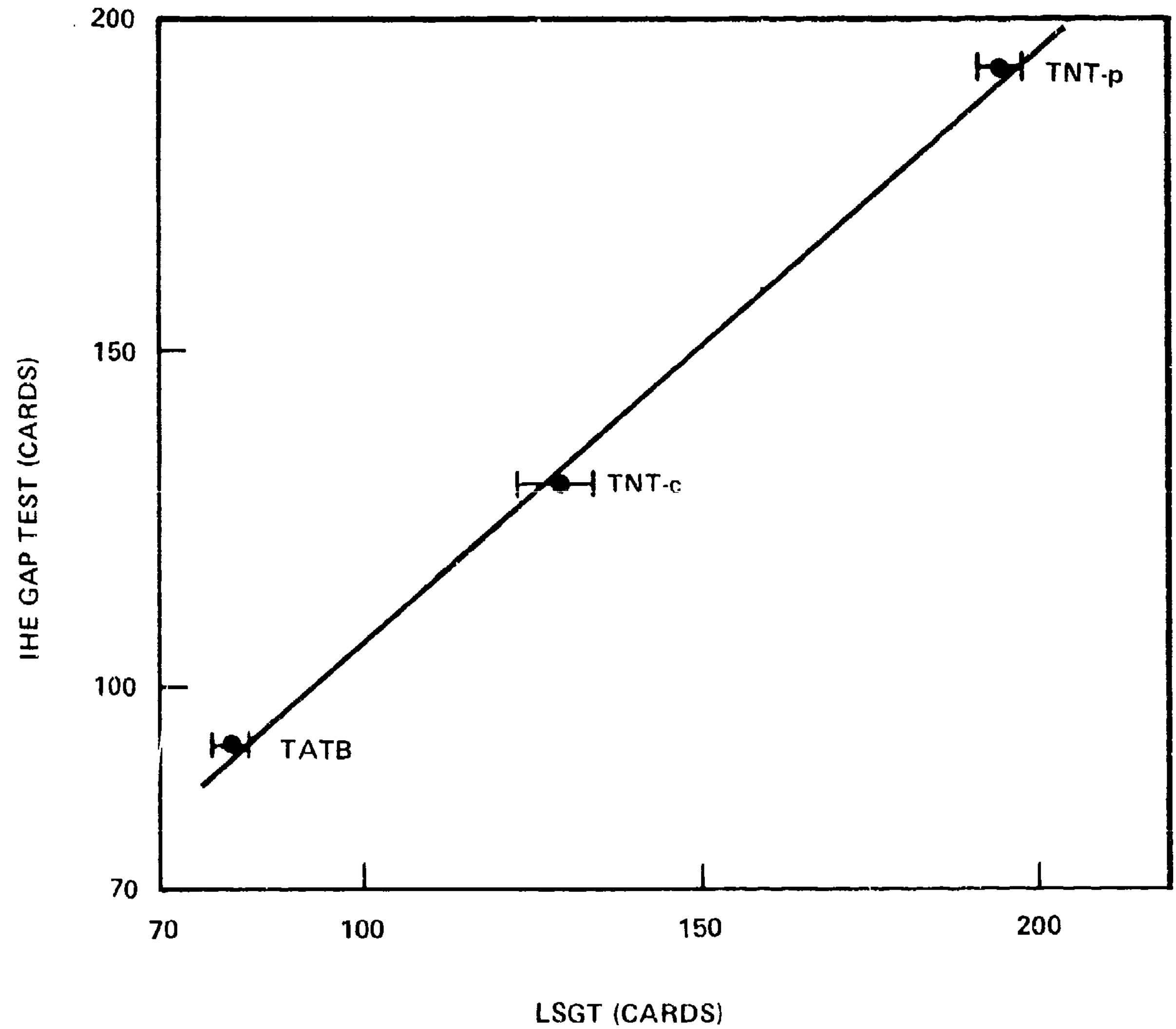



FIG. 4 COMPARISON OF RESULTS FROM LSGT AND IHE GAP

It follows from the illustration of Figure 5 that the demand for larger diameter gap tests is to allow HE of large $d_c$ to be tested at $d \geq 3d_c$. Here $d_c$ refers to effective critical diameter not to the $d_c$ we measure on unconfined charges. Hence, we may decrease the effective $d_c$ by confining the charge as well as by increasing the test charge diameter. With the objective of testing IHE in the proper diameter range, DDESB asked the Center (NSWC/WO) to design a larger test than the standardized NOL LSGT. We designed a gap test for which the acceptor and its confinement were scaled up by a factor of 2. Howevever, because of the manufacturer's available molds, the donor was scaled by only a factor of 1.875. Results from this test, the expanded LSGT, were reported at the March meeting of the JANNAF Working Committee on Hazards.[4] Figure 6 shows the two assemblies that were compared and Figure 7 gives the approximate equivalency curve found for the two tests.

You will note: (1) we have not drawn a straight line as in the other 3 correlations I have shown and (2) within experimental error, we could have drawn a straight line. As was pointed out in the original paper, the uppermost and lowermost points are not as well established as the two mid-points. Until this is done, we shall regard this approximate curve as more general than a straight line.

The scaling up of the NOL LSGT by a factor of two is about the practical limit of increasing the test size. As it was, the witness plates were scaled in thickness but not in length x width because they were then too heavy to handle. Nevertheless, there is a much larger gap test developed at Eglin AFB and reported at the previous DDESB Symposium and also at the 8th Symposium (International) on Detonation last year. This test, called the "super" gap test[5], is compared to the NOL LSGT in Figure 8 where both configurations are drawn to scale. This emphasizes the jump in magnitude of the dimensions.

ble 5 lists the results of the "super" gap test and those of the corresponding NOL LSGT. The latter value for tritonal was listed incorrectly in Reference 5. The 50% "super" gap values were obtained from the text of Reference 5 but the computed pressures ($P_g$) were taken from a chart displayed at the 8th Detonation Symposium. Reference 5 contains a

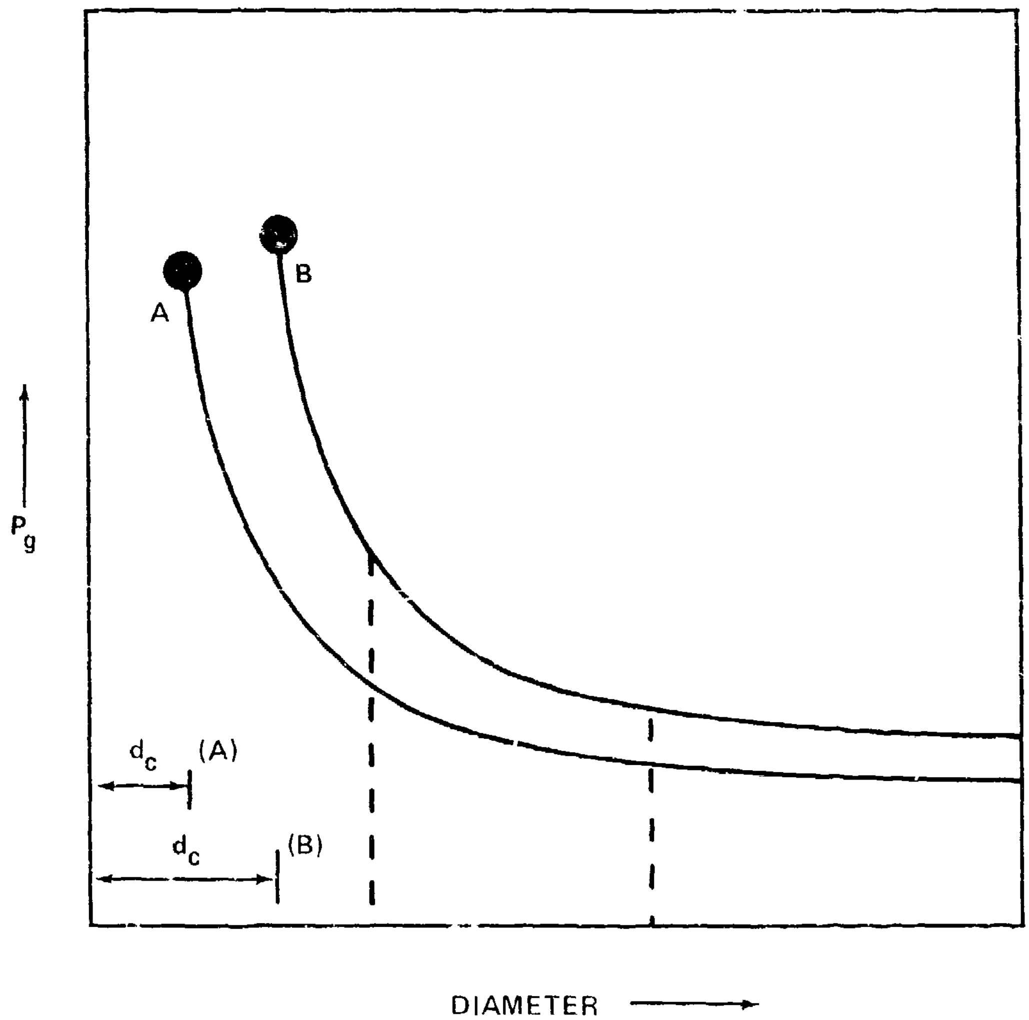



FIG. 5. $P_g$ VS CHARGE DIAMETER FOR EXPLOSIVES A AND B

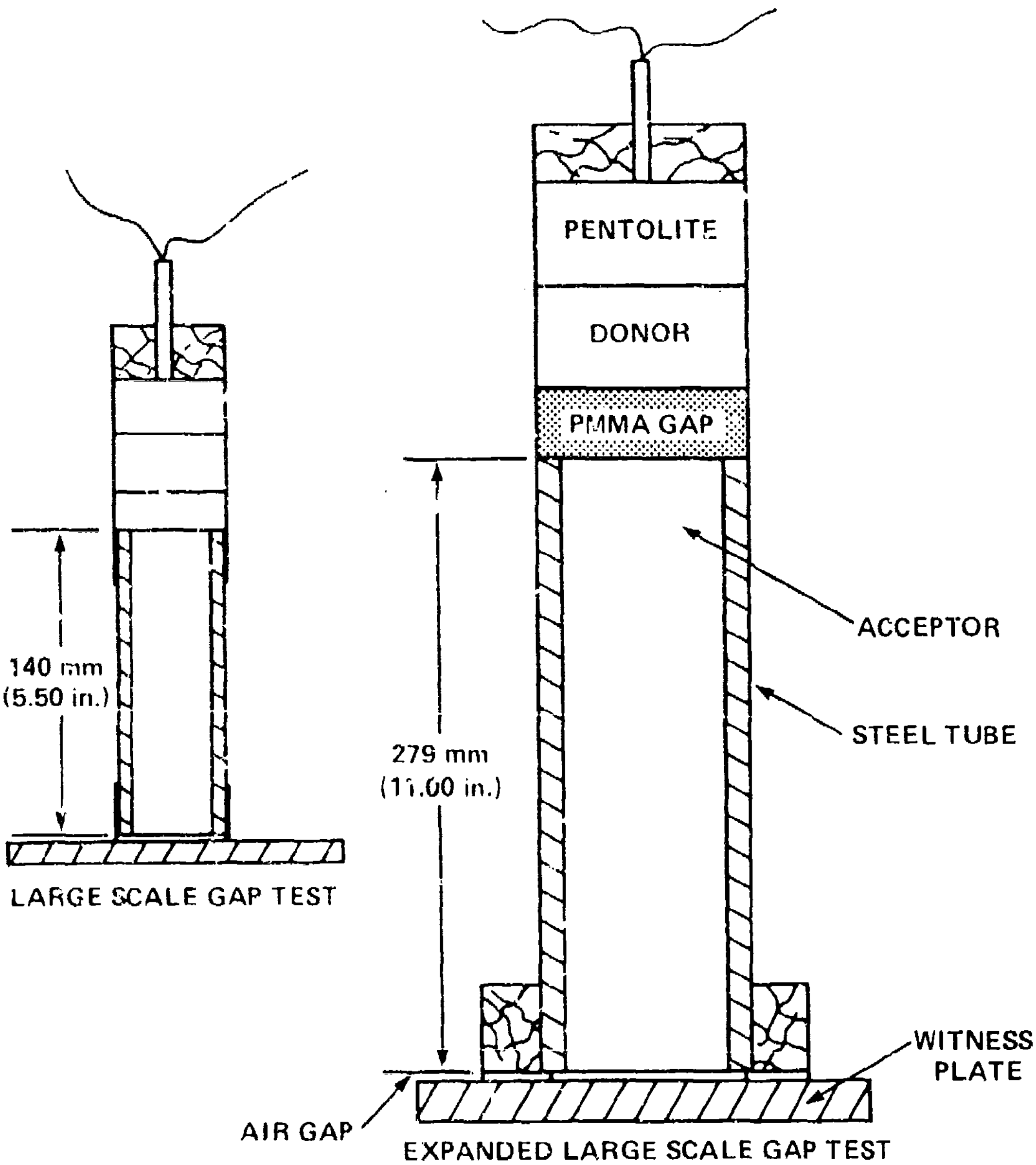



FIG. 6. COMPARISON OF LSGT AND ELSGT ASSEMBLIES

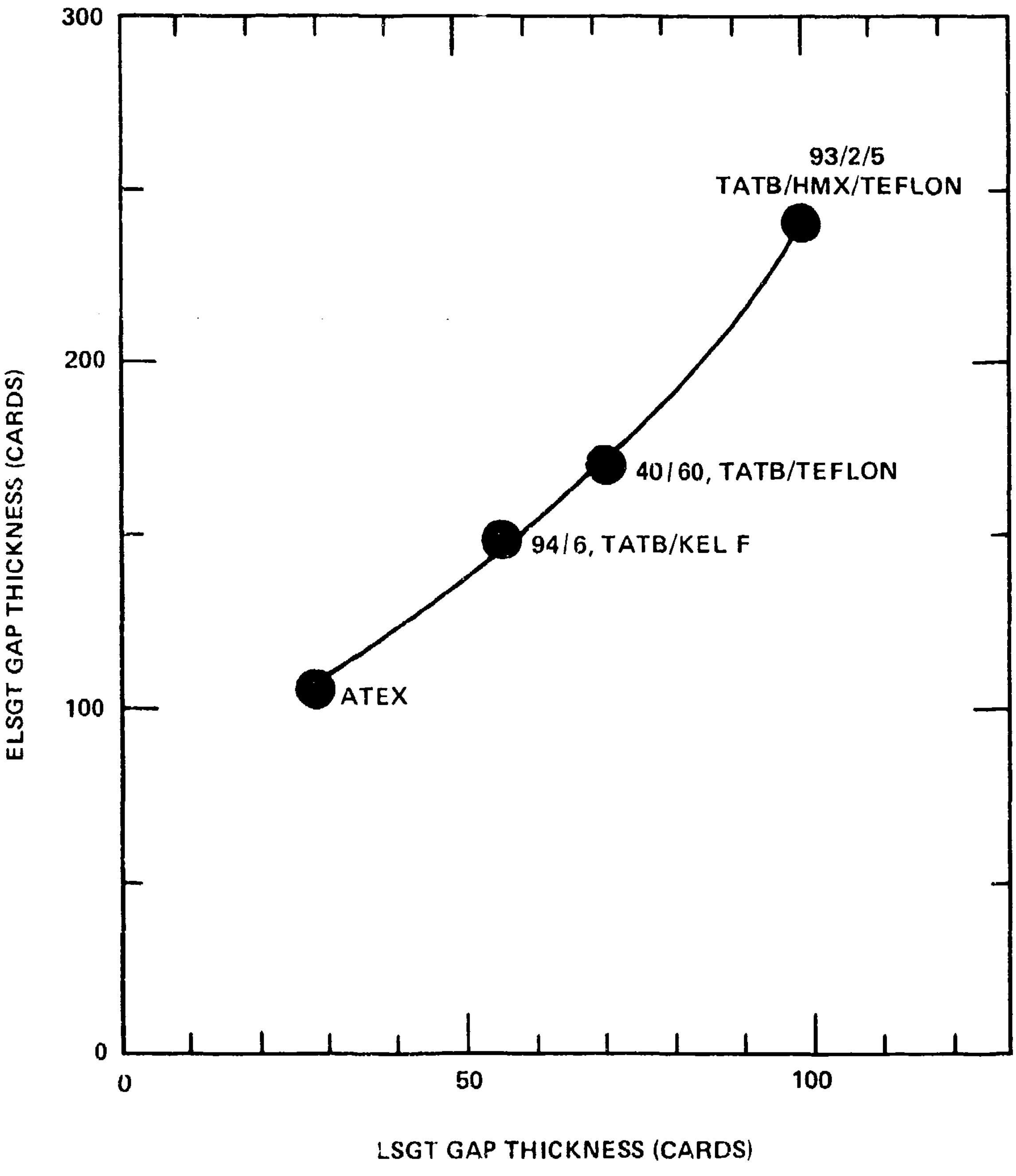
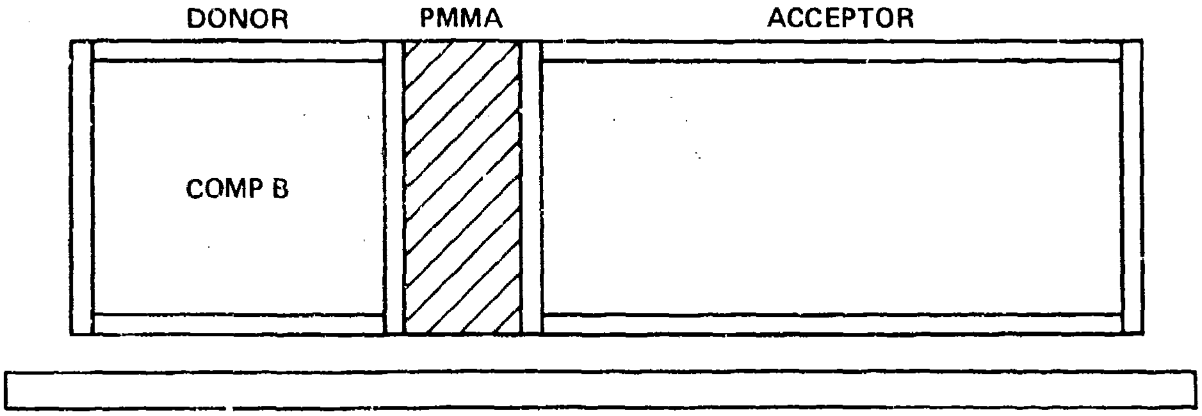



FIG. 7. THE ELSGT 50% GAP THICKNESS VERSUS THE LSGT THICKNESS



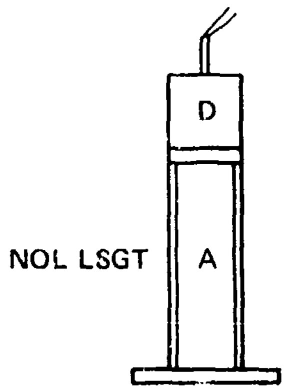




FIG. 8. COMPARISON OF "SUPER" GAP TEST WITH NOL LSGT.

TABLE 5

COMPARISON OF VALUES FROM "SUPER" GAP TEST WITH THOSE OF LSGT

| Cast HE | $\rho_o$ g/cm$^3$ | "Super" Gap 50% Point[a] in. | "Super" Gap $P_g$[b] kbar | NOL LSGT 50% Point in. | NOL LSGT $P_g$ kbar |
|---|---|---|---|---|---|
| Comp B | 1.69 | 7* - 8 | 12 | 2.01-2.07 | 19.7-18.5 |
| Tritonal 80/20 | 1.73 | 5 - 6 | 15 | 1.00-1.01 | 55 |
| TNT/Wax 95/5 | 1.69 | 5* - 6 | 16 | Not Tested | |
| TNT/NQ/Wax 60/35/5 | 1.61 | 2* - 3 | 40 | Failed | |

a. Values found in text of Ref. 5; values with asterisk closer to 50% gap value.

b. Values read from chart displayed at 8th Detonation Symposium

calibration curve (Reference 5, Figure 13) of $P_g$ vs PMMA thickness. However, this curve gives no values for $P_g < 30$ kbar, but Figure 10 seems to extend the computed values to the pressures transmitted from the PMMA through the 0.5 in. steel confining the acceptor charge.

Not only is the scale of the "super" gap test much greater than that of the more widely used tests, but its purpose is also different. It is to "screen for an explosive's propensity to detonate or react violently as a result of shock induced sympathetic detonation of large ordnance such as general purpose bombs" (100 - 1000 kg HE). The more common gap tests are concerned with relative shock sensitivity, an explosive property. Some industrial laboratories classify their tests as property tests or use tests; in the present gathering, we call the latter vulnerability tests. Such tests are carried out when the available basic information is insufficient to permit a reliable prediction by any set of computations. This is essentially the case for the "super" gap test; I consider it a good field test for its specific purpose. Having said that, I will add that use of field tests will continue to demand large charges, but not necessarily many shots.

By way of summary, we have found that three pairs of gap tests of very different design give the same relative shock sensitivity ratings for a number of explosives. The number of data points were 3 - 9, too few, of course, to generalize. But in view of the differences in ratings I have seen from tests coming out of different laboratories, I should not have expected the linear correlations we saw. Despite these, Liddiard and I drew the approximate equivalence curve between the NOL LSGT and the ELSGT as non-linear because it is more general than the straight line and so must stand until better data are available. Finally, anything larger than the ELSGT should be considered a use or field test designed to address a specific problem rather than a test for general application.

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